WADC TECHNICAL REPORT 52-73

MECHANICAL PROPERTIES OF A NEW HIGH-STRENGTH HIGH-TOUGHNESS GENERAL-PURPOSE ALLOY STEEL

WILLIAM E. DIRKES, 1ST LT, USAF
ROBERT E. BOWMAN, MAJOR, USAF
EDWARD L. HORNE

MATERIALS LABORATORY

AUGUST 1952

WRIGHT AIR DEVELOPMENT CENTER

NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The information furnished herewith is made available for study upon the understanding that the Government's proprietary interests in and relating thereto shall not be impaired. It is desired that the Judge Advocate (WCJ), Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, be promptly notified of any apparent conflict between the Government's proprietary interests and those of others.

WADC TECHNICAL REPORT 52-73

MECHANICAL PROPERTIES OF A NEW HIGH-STRENGTH HIGH-TOUGHNESS GENERAL-PURPOSE ALLOY STEEL

William E. Dirkes, 1st Lt, USAF
Robert E. Bowman, Major, USAF
Edward L. Horne

Materials Laboratory

August 1952

RDO No. R604-304

Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

McGregor & Werner, Inc.
Dayton, O. 300, 19 Sept.52

FOREWORD

A new general purpose through-hardening chrome-nickel-molybdenum-vanadium alloy steel (modified SAE 4340 plus vanadium) has been developed and produced by the Republic Steel Corporation. This steel has high ductility and toughness when heat treated to high strengths. Several mechanical property tests have been compared with those for Crucible Steel Company's "Hy-Tuf" high ductility alloy steel and the well established high strength general purpose SAE 4340 alloy steel.

Both low alloy steels were developed to be used in applications where the combination of high strength with high ductility and toughness is of major concern. No trade designation has been given to this alloy steel by the Republic Steel Corporation. The work on this investigation was accomplished by the Materials Laboratory, Research Division, Wright Air Development Center, under Research and Development Order No. R604-304, "Design, Specification and Evaluation Data for Metallic Materials", with Mr. E. L. Horne acting as project engineer.

ABSTRACT

Mechanical properties of a chrome-nickel-molybdenum-vanadium general purpose medium carbon alloy steel (modified SAE 4330 plus vanadium), developed and fabricated by the Republic Steel Corporation, were determined by the Materials Laboratory, Research Division, Wright Air Development Center, to evaluate the suitability of the steel for aircraft applications where the combination of high strength and toughness are required. The properties of the Republic alloy steel were compared with the properties of an alloy steel, designated as "Hy-Tuf", developed by the Crucible Steel Company for the same purpose and with the properties of the well established SAE 4340 general purpose alloy steel. When heat treated to the same nominal hardness and strength levels, the Republic steel had approximately the same percentages of elongation and reduction of area as the other steels. The Republic alloy steel showed superior Izod impact properties to those of Hy-Tuf and SAE 4340 alloy steels when each was heat treated to a tensile strength approximating 170,000 psi (Rockwell C39) both at room and low temperatures, but its impact properties were not as high as those for Hy-Tuf when heat treated to strength levels around 220,000 psi either at room or low temperatures. Both the Republic alloy steel and Hy-Tuf alloy steel had impact properties superior to those of SAE 4340 alloy steel throughout the range of tensile strengths, 170,000 psi to 240,000 psi (Rockwell C39 to Rockwell C50), covered in this investigation, at room temperature and at low temperatures (-67°F or below). The end-quench hardenability curve for the Republic alloy steel fell along the minimum curve for SAE 4340 alloy up to a distance of 3/4 inch from the quenched end of the specimen, beyond which distance it approached the median of the hardenability range for SAE 4340. The Republic steel can be successfully welded by the same procedures used for welding SAE 4340 alloy steel.

PUBLICATION REVIEW

Manuscript Copy of this report has been reviewed and found satisfactory for publication.

FOR THE COMMANDING GENERAL:

M. E. SORTE
Colonel, USAF
Chief, Materials Laboratory
Research Division

TABLE OF CONTENTS

	Page
Material and Procedure	1
Results	3
Discussion	4
Conclusions	5
References	7
Appendix	8

LIST OF TABLES

Table I	Longitudinal Tensile Properties of Republic High Strength Steel 1-1/2" Bar Stock and Other General Purpose Alloy Steels.	8
Table II	Longitudinal Tensile Properties at Various Locations in Heat Treated 4" Diameter Republic High Strength Steel Bars.	11
Table III	Transverse Tensile Properties of Republic High Strength Steel 4" Bar Stock and Another High Strength Alloy.	12
Table IV	Longitudinal Tensile Properties For Welded and Unwelded Republic High Strength Alloy Steel 1/4" Plate.	13
Table V	Izod Impact Properties at Various Locations in Heat Treated 4" Diameter Republic High Strength Steel Bars, 3 Notch Specimens.	14
Table VI	Impact Properties of Republic High Strength Steel Heat Treated in 1-1/2" Diameter Bars Compared With Other General Purpose Alloy Steels. Tests Made at Room and Low Temperatures.	15

LIST OF ILLUSTRATIONS

		Page
Figure 1	Positions in 4 inch Diameter Steel Rounds From Which Specimens Were Taken After Heat Treatment was Completed.	17
Figure 2	Hardness Traverses at Mid-Lengths of 12-inch Long 4 inch Diameter Round Republic Alloy Steel Bars.	18
Figure 3	A.S.T.M. Tentative Method of End-Quench Test for Hardenability of Steel.	19
Figure 4	Details of Welding Procedure.	20
Figure 5	Comparison of Transverse and Longitudinal Yield Strength Properties of Republic Alloy Steel. Specimens cut from 4" diameter bars.	21
Figure 6	Comparison of Transverse and Longitudinal Ultimate Strength Properties of Republic Alloy Steel. Specimens Cut from 4" Diameter Bars.	22
Figure 7	Comparison of Transverse and Longitudinal Reduction of Area of Republic Alloy Steel. Specimens Cut from 4" Diameter Bar.	23

MATERIAL AND PROCEDURE

The material consisted of three lots of low alloy medium carbon general purpose steel, Heat No. 657744, developed and produced by the Republic Steel Corporation. (See Reference 1) The three lots consisted of 4 inch diameter round bar, 1-1/2 inch diameter round bar and 1/4 inch thick plate. The chemical composition of the 1-1/2 inch diameter round bar was determined by the Materials Laboratory and the analytical results along with the nominal composition submitted by Republic Steel Corporation are given below (Reference 1). The nominal compositions for "Hy-Tuf" (Reference 2) and SAE 4340 (Reference 3) alloy steels are also given.

	Republic Steel(1)	Republic Steel(2)	"Hy-Tuf"(2)	SAE 4340(3)
Carbon	0.29	0.31	0.25	0.40
Manganese	0.86	0.87	1.30	0.70
Silicon	0.30	0.30	1.50	0.30
Nickel	1.78	1.82	1.80	1.85
Chromium	0.76	0.74	None	0.75
Molybdenum	0.46	0.43	0.40	0.25
Vanadium	0.08	0.10	None	None

(1) Analysis by Materials Laboratory
(2) Nominal composition submitted by manufacturer
(3) Typical analysis

Parts of the three lots of the Republic steel were given two or more of the following heat treatments:

Lot	Oil Quenched at 1550°F. Tempered at 1150°F.	Oil Quenched at 1550°F. Tempered at 700°F.	Oil Quenched at 1550°F. Tempered at 500°F.	Normalized at 1600°F.
4" Round	Yes	Yes	no	no
1-1/2" Round	Yes	Yes	Yes	no
1/4" Plate	Yes	Yes	Yes	Yes

All longitudinal 1/2 inch diameter tensile specimens and all transverse 1/4 inch diameter subsize tensile specimens were prepared in accordance with Federal Specification QQ-M-151a, "Metals; General Specification for Inspection of" (Reference 4), while the longitudinal 1/4 inch diameter subsize specimens conformed to the same requirements except that their gage sections were modified to 8D instead of 4D, as specified, in order that an extensometer for a 2 inch gage length could be used. Standard testing procedures and equipment were used in accordance with Federal Specification QQ-M-151a including 4D elongation percentage measurements in all cases.

The Izod impact specimens were 3-notch specimens having V-notches and cross sectional dimensions in accordance with Federal Specification QQ-M-151a(Reference 4). Each notch was 1.1 inch from the specimen end or the next notch so that as successive breaks were made across the notches, the unsupported section of the specimen during each test was at a standard distance from the vise of the impact testing machine.

Standard 1/2 inch diameter and modified 1/4 inch diameter round tensile specimens and 3-notch standard Izod impact specimens were cut from the center of 1-1/2 inch diameter bar stock and tested at room temperature. Additional Izod impact specimens were tested at -67°F in a cold temperature chamber, after a 24 hour soaking period.

Jominy end-quench hardenability specimens were also cut from the center of the 1-1/2 inch round bar stock and were tested in accordance with Amendment 3 of Federal Specification QQ-M-151a (Reference 4).

Twelve-inch lengths of 4" diameter round bar stock were heat treated and tempered. Modified 1/4 inch diameter longitudinal tensile, Izod impact, hardness and standard subsize 1/4 inch diameter transverse tensile specimens were then cut from locations as shown in Figure 1. The standard tensile, transverse tensile and Izod impact specimens were tested in standard equipment using standard procedures. Rockwell C hardness traverses were taken across the ground surfaces of the 1 inch thick disc shown in Figure 1.

Standard flat tensile specimens were cut from the 1/4 inch thick plate in accordance with Federal Specification QQ-M-151a. Welding plates were cut from the 1/4 inch thick stock in accordance with Figure 3 of ANA Specification AN-T-38a,"Tests; Aircraft Welding Operators' Certification" (Reference 5). The plates were cut so that the direction of rolling of the plate coincided with the lengths of specimens cut from the plate. The plates were butt-welded with an electric arc in accordance with ANA Specification AN-T-38 using 1/8 inch diameter Harnischfeger, type P&H #21 welding electrode, which conformed to Class D of ANA Specification AN-E-9 "Electrodes; Mild and Alloy Steel Welding" (Reference 6). The manufacturer gave the following information on the strength of the deposited metal:

	Ultimate Tensile Strength Psi	Yield Strength Psi	Elongation %
As welded	142,500	125,000	9
Normalized at 1650°F	125,000	77,000	21.5

Before welding, the edges of the plates were bevelled 45° across 3/4 of the plate thickness, as shown in Figure 4; other information pertinent

to the welding operations is also contained in Figure 4. Welded plates were heat treated in accordance with the above chart. One set of plates was also made into specimens and tested in the "as-welded" condition.

RESULTS

The minimum ultimate tensile strengths of heat treated 1/2 inch and 1/4 inch round specimens, from the 1-1/2 round bar, after oil quenching from 1550°F and tempering at 1150°F, were 170,000 psi and 166,100 psi respectively with corresponding yield strengths of 161,600 psi and 157,200 psi, elongations in a 4D gage length of 15% and 17%, and reductions of area of 54% and 55%. The minimum ultimate tensile strength of 1/4 inch thick plate, after the same treatment, was 175,600 psi with yield strength of 167,500 and elongation in 2 inches of 13%. Additional tensile data for material normalized at 1550°F and tempered at 500°F and at 700°F can be found in Table I. Also given in Table I are tensile and hardness properties for SAE 4340 alloy steel (Reference 7) and "Hy-Tuf" alloy steel (Reference 2).

After the 4 inch diameter bar stock in 12 inch lengths was heated to 1550°F., oil quenched and tempered at 700°F and at 1150°F, test specimens were machined from the stock. Ultimate longitudinal tensile strengths of the material tempered at 1150°F varied from 138,700 psi at the center to a maximum of 152,100 psi at 4/5 of the bar radius from the bar center. Corresponding yield strengths varied from 125,000 psi to 142,300 psi. Additional longitudinal tensile data are contained in Table II. The positions from which tensile specimens were taken from the 4 inch diameter bars are shown in Figure 1.

Transverse 1/4" diameter round tensile specimens were also taken from 4 inch diameter 12 inch long round bars from which 1/4 inch diameter modified longitudinal tensile specimens had been taken. Ultimate transverse tensile strengths ranged from 136,800 psi at the center of stock tempered at 1150°F to a maximum of 146,000 psi at 1 inch from the center of the bar. Corresponding yield strengths varied from 120,400 psi to 134,000 psi with elongations of 15% and 13.5% and reductions of area of 44% and 39%, respectively. Additional transverse tensile data and comparative data are contained in Table III, and Figures 5, 6 and 7. The positions from which specimens were taken from the 4 inch diameter bars are shown in Figure 1. Comparative reductions of area of specimens taken in the longitudinal and transverse directions, as shown in Figure 7, indicate the comparative ductility of the material in the two directions.

Rockwell C hardness values were taken from 1 inch discs cut from the 12 inch long 4 inch diameter bar stock, as shown in Figure 1. Values varied from a minimum of 36.0 near the center of bar stock tempered at 700°F, to a maximum of 43.5 near the outer rim. Similar positions in 4" bar stock

tempered at 1150°F gave a minimum of 28.5 to a maximum of 31 Rockwell C, respectively. Additional hardness values across the face of 4 inch bar stock are shown in Figure 2.

Standard 3-notch Izod impact specimens were also machined from 4 inch diameter bar stock, as shown in Figure 1. Minimum impact values for stock tempered at 1150°F and at 700°F were 63 ft lbs. and 13 ft lbs. respectively. Additional impact and hardness values from the 4 inch diameter bar stock are given in Table V.

Minimum Izod impact test values from 1-1/2 inch round bar stock, oil quenched from 1550°F and tempered at 500°F, 700°F and 1150°F, were 29, 25 and 59 ft lbs, respectively. The corresponding values at low temperature (-67°F) were 19, 15 and 53 ft lbs. The values from each temperature range were consistent. Additional impact and hardness values from the 1-1/2 inch diameter bar stock are given in Table VI along with impact properties for SAE 4340 and Hy-Tuf alloy steels (References 2 and 7).

The end-quench hardenability curve for this heat of Republic steel, for 3/4 of an inch, fell along the minimum curve for SAE 4340 alloy steel, as shown in Figure 3 (Reference 8). Beyond one inch from the end of the specimen, the curve fell slightly below the average of the hardenability for SAE 4340 steel. Flat plate specimens 1/4" thick, oil quenched at 1550°F and tempered at 1150°F had an average tensile strength of 176,700 psi. Specimens which were arc welded with electrodes conforming to Class D of ANA Specification AN-E-9 and then heat treated the same as above had an average tensile strength of 174,900 psi. Additional tensile values for welded and unwelded plate stock are listed in Table IV. Low ultimate tensile strengths were obtained from some of the welded joints, due to incomplete penetration at the root of the weld. The majority of the specimens contained small blowholes but the reduction in strength due to these blow holes was small. All defects were in the weld metal and there were no cracks found in the parent metal adjacent to the weld. With additional experience in welding the material, the blow hole defects could be practically eliminated. The alloy can be welded using the same procedures required for SAE 4340 steel.

DISCUSSION

The analysis in this report of Heat 657744 from Republic Steel Corporation was in good agreement with the nominal analysis published by the manufacturer. Hardness traverses through the 4 inch diameter bars, as shown in Figure 2, indicate a through hardening steel. End quench hardenability, as shown in Figure 3, is very similar to end quench hardenability curves for Hy-Tuf and lies generally within the minimum values determined for SAE 4340 steel.

The Izod impact properties of this Republic alloy steel have only a small reduction at low temperature (-67°F±3°F). The Republic Steel showed superior impact properties when heat treated to a tensile strength approximating 170,000 psi both at room and low temperatures, but its impact properties were not as high as those for Hy-Tuf when heat treated to strength levels around 220,000 psi. either at room or low temperatures.

The Republic alloy has about the same weldability as SAE 4340 alloy steel when the same welding practices are used. Although small blowholes were noticeable in the majority of the test specimens, they did not decrease the strength of the weld appreciably. The blowholes were probably caused by the welding technique or the electrode used and are not to be considered characteristic of the steel. Since the welded specimens generally failed in the weld zone, their tensile strengths were dependent upon the properties of the weld material used. In some cases there was incomplete penetration at the root of the weld. Both the blowholes and the incomplete penetration at the root of the weld may be avoided as more experience is acquired in welding the Republic alloy steel.

No comparison was made between the weld test results for the Republic steel and weld test results for the Hy-Tuf steel, given in Air Force Technical Report 5757 (Reference 2), because different trade brands of welding rods (probably having different compositions) were used.

CONCLUSIONS

The mechanical properties obtained for the Republic chrome-nickel-molydenum-vanadium general purpose alloy steel in this investigation conformed generally to data given by the Republic Steel Corporation in Laboratory Report No. 7165-14, "Experimental Testing of a Heat of High Tensile Alloy Steel. Heat 657744", dated 22 September 1949, except that Republic reported higher tensile yield and ultimate tensile strengths for the 500°F and 700°F tempering temperatures than were obtained by the Materials Laboratory.

When heat treated to the same nominal hardness and strength levels as SAE 4340 and Hy-Tuf alloy steels, the Republic alloy steel had approximately the same percentages of elongation and reduction of area as the other steels.

Hardness traverses taken across 4 inch diameter discs cut at mid length from 12 inch long heat treated sections and hardness traverses taken on end-quench hardenability specimens show only slight variation in hardness throughout the Republic alloy steel, indicating that the material is of uniform composition and quality with no discernable non-homogeneities of appreciable magnitude.

Comparison of transverse and longitudinal tensile data shows that the Republic alloy steel, like other wrought alloy steels, is less ductile in the transverse direction than in the longitudinal direction.

When subjected to the same welding practice as SAE 4340 alloy steel, the Republic alloy steel can be welded successfully.

The Izod impact values for the Republic chrome-nickel-molybdenum-vanadium alloy steel were considerably higher than those for Hy-Tuf alloy steel at both room and low temperatures when heat treated to a tensile strength of approximately 170,000 psi (Rockwell C39), but had lower impact strength than Hy-Tuf when heat treated to strengths above 220,000 psi (Rockwell C46). Both steels have better impact values than SAE 4340 alloy steel in the heat treating ranges investigated both at room and low temperatures.

REFERENCES

1. Experimental Testing of a Heat of High Tensile Alloy Steel. Heat 657744, Republic Steel Corporation Laboratory Report No. 7165-14, 22 September 1949.

2. Horne, E. L. Mechanical Properties of a General Purpose Low Alloy Steel Designated as "Hy-Tuf". United States Air Force Technical Report No. 5757, United States Air Force, Air Materiel Command, January 1949.

3. Army-Navy Aeronautical Specification AN-QQ-S-756a Steel; Chrome-Nickel-Molybdenum (4340) Bar and Rod.

4. Federal Specification QQ-M-151a Metals; General Specification for Inspection of.

5. Army-Navy Aeronautical Specification AN-T-38a Tests; Aircraft Welding Operators Certification.

6. Army-Navy Aeronautical Specification AN-E-9 Electrodes; Mild and Alloy Steel Welding.

7. Hoyt, S. L. Metals and Alloys Data Book. First edition. Reinhold Publishing Corporation, New York, 1943.

8. Hardenability of Alloy Steels. Contributions to the Metallurgy of Steel No. 11, by American Iron and Steel Institute and the Society of Automotive Engineers.

APPENDIX I

TABLE I

Longitudinal Tensile Properties of Republic High Strength Steel 1-1/2" Bar Stock and Other General Purpose Alloy Steels

Specimen(1)	Specimen Diameter Inch	Yield Strength 0.2% Offset Psi	Ultimate Strength Psi	Elongation in 2 Inches %	Elongation in 1 Inch %	Reduction of Area %	Hardness Rockwell C
Oil Quenched From 1525-1575°F; Tempered at 1150°F							
Republic H-1	1/2	161,600	170,100	15.5	—	55	39
H-2	1/2	161,900	170,000	16	—	56	39
H-3	1/2	162,000	170,000	15	—	54	40
R-1(2a)	1/2	163,500	167,500	17	—	55	38(3)
H-4	1/4	157,200	166,900	—	17	58	40
H-5	1/4	158,800	166,100	—	17.5	59.5	40
H-6	1/4	160,200	167,300	—	—	—	39
Oil Quenched From 1475-1525°F; Tempered at 1000°F							
SAE 4340(4)	1/2	160,000	184,000	15	—	52	39
Oil Quenched From 1575-1600°F; Tempered at 1050°F							
Hy-Tuf(5)	1/2	154,700	169,000	16.5	—	52	38
Oil Quenched From 1525-1575°F; Tempered at 700°F							
Republic M-1	1/2	195,100	216,100	12	—	51	46
M-2	1/2	195,000	216,400	12	—	53	47
M-3	1/2	195,400	217,500	12	—	50	48
R-2(3a)	1/2	205,500	222,500	12	—	49	46(3)
M-4	1/4	—	211,000	—	14	57	47
M-5	1/4	194,200	212,300	—	14.5	55	45
M-6	1/4	194,200	210,900	—	14	57	45

TABLE I(continued)

Longitudinal Tensile Properties of Republic High Strength Steel 1-1/2" Bar Stock and Other General Purpose Alloy Steels

Specimen(1)	Specimen Diameter Inch	Yield Strength 0.2% Offset Psi	Ultimate Strength Psi	Elongation in 2 Inches %	Elongation in 1 Inch %	Reduction of Area %	Hardness Rockwell C
Oil Quenched From 1475-1525°F; Tempered at 800°F							
SAE 4340(4)	1/2	200,000	222,000	13	—	48	46
Oil Quenched From 1575-1600°F; Tempered at 700°F							
Hy-Tuf(5)	1/2	190,700	227,500	13	—	51	48
Oil Quenched From 1525-1575°F; Tempered at 500°F							
Republic L-1	1/2	200,800	238,000	13	—	49	49
L-2	1/2	199,900	239,100	13	—	49	50
L-3	1/2	199,900	238,700	12	—	49	50
R-3(2b)	1/2	222,000	247,500	12	—	48	49(3)
L-4	1/4	196,400	234,100	—	14.5	54	50
L-5	1/4	195,400	233,100	—	14	55	49
L-6	1/4	199,200	234,100	—	—	—	48
Oil Quenched From 1475-1525°F; Tempered at 800°F.							
SAE 4340(4)	1/2	200,000	222,000	13	—	48	46
Oil Quenched From 1575-1600°F; Tempered at 500°F							
Hy-Tuf(5)	1/2	189,000	232,700	13	—	48	49

NOTES:

(1) All Republic Steel and Crucible Steel specimens were machined from center of cross-section of bar. Information as to specimen location was not available for the SAE 4340 data.

(2) Data published by Republic Steel Corporation (a) for specimens treated in 1" rounds, (b) for specimens treated in 0.503" rounds.

NOTES from Table I (continued)

(3) These Rockwell C hardness values were converted from Brinell hardness values given by use of conversion chart in Federal Specification QQ-M-151a "Metals; General Specification for Inspection of".

(4) Data for 4340 alloy steel given in Table 106 (p-77) of Hoyt's "Metals and Alloy Data Book".

(5) Data for "Hy-Tuf", product of Crucible Steel Company of America, is the average from Table I (p-7) of Air Force Technical Report 5757.

TABLE II

Longitudinal Tensile Properties at Various Locations in Heat Treated 4" Diameter Republic High Strength Steel Bars (1)

1/4 inch diameter specimens

Specimen Number	Distance From Specimen Center To Center of Bar Fifths of Bar Radius (2)	Yield Strength 0.2% Offset psi.	Ultimate Strength Psi.	Elongation in 1 inch %	Reduction of Area %	Average Hardness Rockwell C
	Oil Quenched From 1550°F; Tempered at 1150°F					
H-11	4	141,700	152,100	19	62	36
H-12	2	131,400	142,800	19	62	33
H-13	0	125,000	138,700	20	63	31
H-14	2	130,700	143,200	19	62	32
H-15	4	142,300	151,800	19.5	61	36
	Oil Quenched from 1550°F; Tempered at 700°F					
M-11	4	200,800	224,700	12.5	49	48
M-12	2	164,200	190,700	14	56	47
M-13	0	150,000	179,700	14	59	45
M-14	2	170,000	195,500	12	55	47
M-15	4	196,200	221,200	12	51	48

NOTES: (1) The 4" diameter bars were 12" in length. Specimens were machined from them after completion of heat treatment.

(2) The length of each specimen was parallel to the length of the bar from which it was taken.

TABLE III

Transverse Tensile Properties of Republic High Strength Steel 4" Bar Stock and Another High Strength Alloy (1)

Specimen Number	Distance from Specimen Center To Center of Bar Inches	Yield Strength 0.2% Offset psi	Ultimate Strength psi	Elongation in 1 Inch %	Reduction of Area
	Oil Quenched From 1525-1575°F; Tempered at 1150°F				
Republic H-6	1.0	134,000	146,000	13.5	39
H-7	0.5	122,300	138,700	16	43
H-8	0	120,400	136,800	15	44
H-9	0.5	123,100	138,900	14	42
H-10	1.0	131,300	144,400	14	39
	Oil Quenched From 1575-1600°F; Tempered at 1050°F				
Hy-Tuf(2) 1	1.0	134,600	155,700	15	37
2	0.5	128,600	148,900	14	33
3	0	123,400	145,600	12.5	30
4	0.5	129,900	150,300	13.5	33
5	1.0	137,900	154,800	14.5	37
	Oil Quenched From 1525 - 1575°F; Tempered at 700°F				
Republic M-6	1.0	182,000	203,000	8	31
M-7	0.5	154,500	181,800	7.5	28
M-8	0	149,900	172,000	8	29
M-9	0.5	159,300	184,200	8	30
M-10	1.0	189,300	209,500	7.5	26
	Oil Quenched From 1575-1600°F; Tempered at 700°F				
Hy-Tuf(2)1	1.0	163,500	182,300	11.5	37
2	0.5	150,000	167,700	11	37
3	0	150,000	164,300	10.5	33
4	0.5	154,800	172,100	11	38
5	1.0	165,300	184,600	11	38

NOTES: (1) Locations of Republic Steel Specimens in 4" Diameter Bar are shown in Figure 1.
(2) Materials Laboratory Data Not Previously Published.

TABLE IV

Longitudinal Tensile Properties For Welded and Unwelded Republic High Strength Alloy Steel 1/4" Plate

Specimen Number	Type of Specimen (1)	Welded or Unwelded	Yield Strength 0.2% Offset psi	Ultimate Strength psi	Elongation in 2 inches %	Average(2) Hardness Rockwell C	Failure
			Normalized at 1600°F (Before Welding)				—
UN 4	Standard	Unwelded	164,000	238,200	9	51	—
5	"	"	176,000	256,400	9	53	—
6	"	"	188,100	255,700	9	53	—
1	3 Gage	"	—	234,300	10	51	—
2	"	"	—	235,800	10	49	—
3	"	"	—	240,300	9	51	—
WN 1	"	Welded	—	161,500	2	52	In Weld Zone
2	"	"	—	167,300	2	47	In Weld Zone
3	"	"	—	180,000	3	48	In Weld Zone
			Oil Quenched from 1550°F Tempered at 500°F (After Welding)				
UL 4	Standard	Unwelded	219,300	251,800	9	50	—
5	"	"	220,000	250,200	10	50	—
6	"	"	216,400	251,300	10	49	—
1	3 Gage	"	—	242,300	11	50	—
2	"	"	—	—	10	51	—
3	"	"	—	245,000	10.5	50	—
WL 1	"	Welded	—	220,700	3	51	In Weld Zone
2	"	"	—	202,100(3)	2.5	50	In Weld Zone
3	"	"	—	228,900	4	49	In Weld Zone
			Oil Quenched from 1550°F; Tempered at 700°F (After Welding)				
UM 4	Standard	Unwelded	201,000	222,700	10	48	—
5	"	"	202,000	220,400	10	48	—
6	"	"	198,000	218,900	9	48	—
1	3 Gage	"	—	222,200	10	47	—
2	"	"	—	223,300	9	48	—
3	"	"	—	223,800	10	47	—
WM 1	"	Welded	—	197,200	3.5	48	In Weld Zone
2	"	"	—	208,700	3	48	In Weld Zone
3	"	"	—	211,200	4	48	In Weld Zone
			Oil Quenched from 1550°F; Tempered at 1150°F (After Welding)				
UH 4	Standard	Unwelded	167,900	177,000	13	41	—
5	"	"	168,600	177,200	13	40	—
6	"	"	167,500	175,600	13	41	—
1	3 Gage	"	—	177,000	15.5	42	—
2	"	"	—	175,700	15	42	—
3	"	"	—	177,400	15.5	41	—
WH 1	"	Welded	—	174,900(3)	4	42	In Weld Zone
2	"	"	—	172,800(3)	4.	41	In Weld Zone
3	"	"	—	176,900(3)	13.5	41	Outside Weld Zone

NOTES:

(1) Standard specimens were prepared in accordance with Federal Specification QQ-M-151a, "Metals; General Specification for Inspection of,"; specimens having 3" gage lengths were prepared in accordance with drawings in ANA Specification AN-T-38a "Tests; Aircraft Welding Operators Certification".

(2) Hardness values from ends of fractured tensile specimens.

(3) Incomplete penetration at root of weld.

TABLE V

Izod Impact Properties at Various Locations in Heat Treated 4" Diameter Republic High Strength Steel Bars, (1) 3 Notch Specimens (Room Temperature)

Specimen Number(2)	Distance From Specimen Center to Center of Bar, Fifths of Bar Radius	Izod Impact Value Foot - Pounds			Average Hardness Rockwell C	
		1st Notch	2nd Notch	3rd Notch	Near Mid-Length	Near Outside End
	Oil Quenched From 1550°F; Tempered at 1150°F					
H-1	4	65	65	66	36	36
H-2	2	74	76	76	35	33
H-3	0	76	76	76	32	31
H-4	2	72	74	74	33	33
H-5	4	65	63	67	36	35
	Oil Quenched From 1550°F; Tempered at 700°F					
M-1	4	14	14	16	48	46
M-2	2	20	19	18	41	43
M-3	0	19	20	20	39	42
M-4	2	17	18	18	45	41
M-5	4	15	15	13	48	48

NOTES: (1) The 4" diameter bars were 12" in length. Specimens were machined from one end after completion of heat treatment.

(2) The length of each specimen was parallel to the length of the bar from which it was taken; the first notch across which specimens were fractured was nearest mid-length of the 12" bar.

TABLE VI

Impact Properties of High Strength Steel Heat Treated in 1-1/2" Diameter Bars Compared With Other General Purpose Alloy Steels. Tests Made at Room and Low Temperatures.

Specimen (1)	Ultimate Tensile Strength Psi	Hardness Rockwell C	Test Temperature	Izod Impact Value Ft. Lbs. 1st Notch	2nd Notch	3rd Notch	Average
Oil Quenched From 1525-1575°F; Tempered at 1150°F							
Republic	170,000	39	Room	60	61	59	60
Republic	--	--	-67°F	54	55	53	54
Oil Quenched From 1475-1525°F; Tempered at 1050°F							
Hy-Tuf(2)	169,000	38	Room	42	43	45	43.5
Hy-Tuf(2)	--	--	-88°F	26	20	18	21.5
Oil Quenched From 1525-1575°F; Tempered at 700°F							
Republic	216,000	46	Room	27	26	25	26
Republic	--	--	-67°F	17	16	15	16
Oil Quenched From 1600°F; Tempered at 700°F							
Hy-Tuf(2)	228,000	47.5	Room	29.5	28	29.5	29
Hy-Tuf(2)	--	--	-88°F	20	20	20	20
Oil Quenched From 1475-1525°F; Tempered at 800°F							
4340(3)	222,000	46	Room	--	--	--	12.5(4)
4340	--	--	-94°F	--	--	--	5 (4)
Oil Quenched From 1525-1575°F; Tempered at 500°F							
Republic	238,000	50	Room	32	30	29	30
Republic	--	--	-67°F	20	21	19	20
Oil Quenched From 1600°F; Tempered at 500°F							
Hy-Tuf(2)	233,000	48.5	Room	32	30	31	31
Hy-Tuf(2)	--	--	-88°F	24	27	24	25

NOTES FROM TABLE VI (continued);

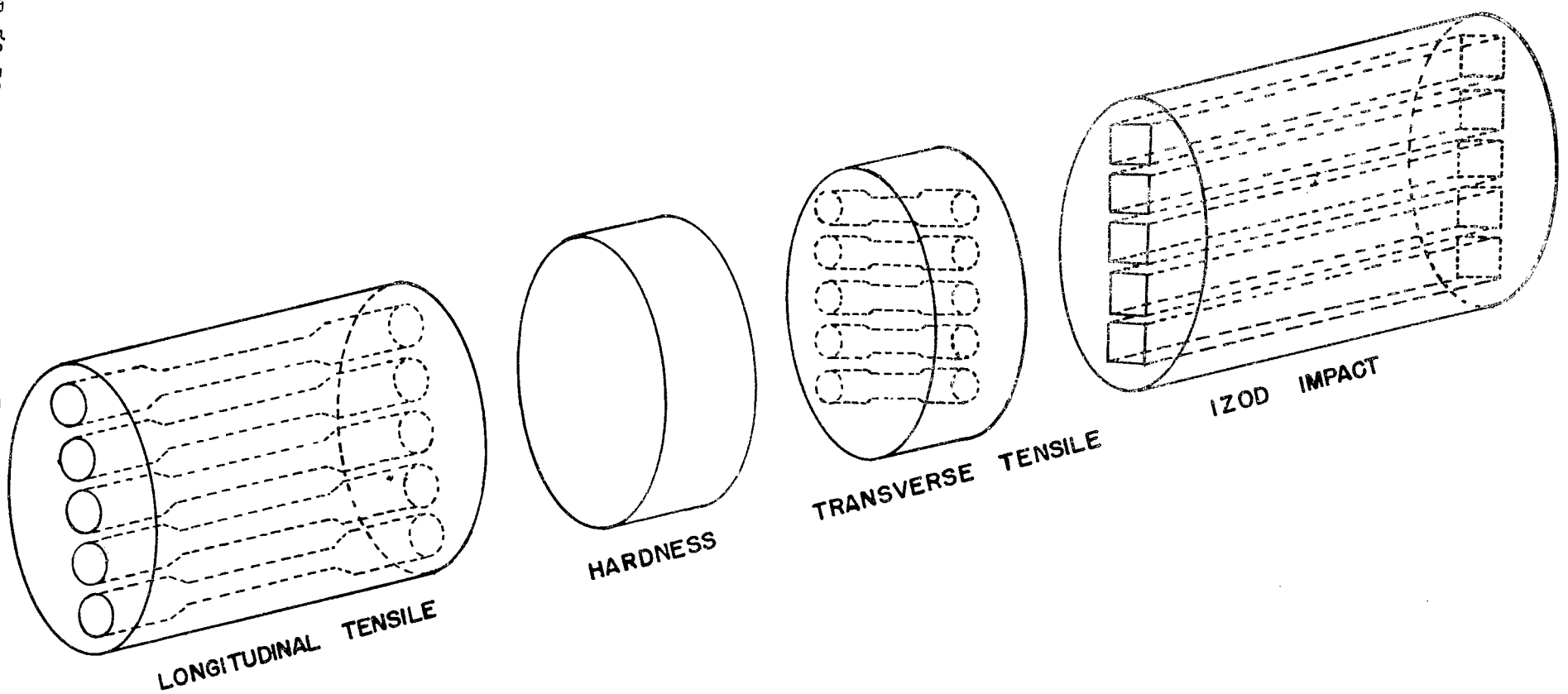
(1) All Republic Steel specimens in this investigation were machined from center of cross-section of 1-1/2 inch diameter round bar stock.

(2) Hy-Tuf data given in Table V (p-12) of Air Force Technical Report 5757.

(3) Data for 4340 alloy steel given in Table 106 (p-77) of Hoyt's "Metals and Alloys Data Book".

(4) This impact value is the average of Izod impact strengths of 4340 steel taken from Tables 106 (p-77) and 165 (p-125) in Hoyt's "Metals and Alloys Data Book".

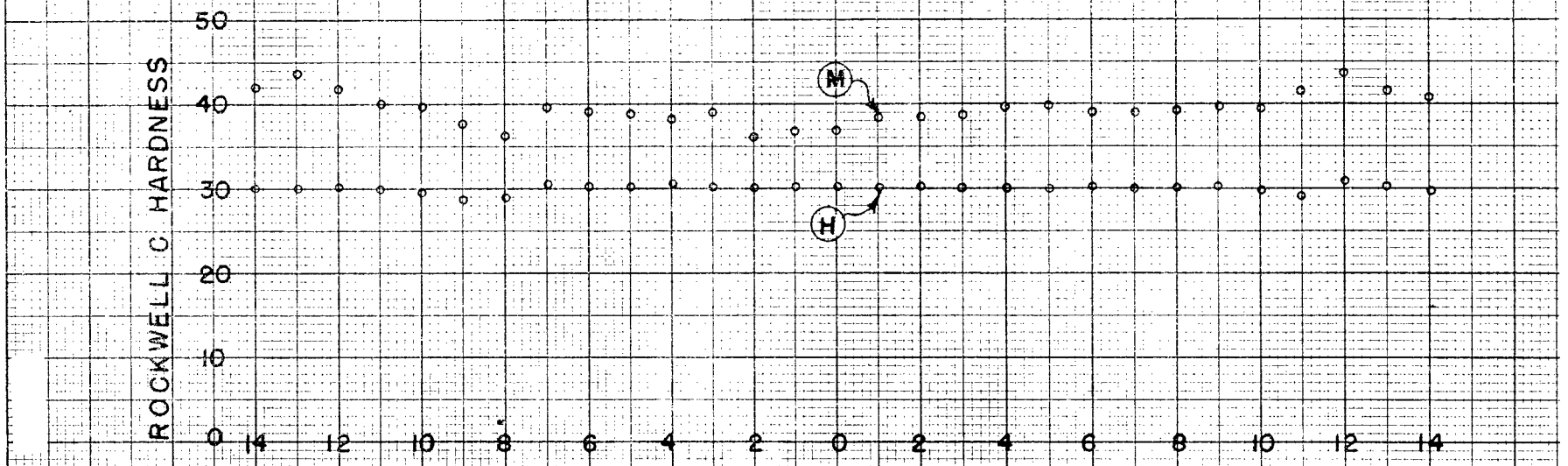
FIGURE 1



POSITIONS IN 4-INCH DIAMETER REPUBLIC STEEL ROUNDS FROM WHICH SPECIMENS WERE TAKEN AFTER HEAT TREATMENT WAS COMPLETED

FIGURE 2

HARDNESS TRAVERSES AT MID-LENGTHS OF 12 INCH LONG 4 INCH DIAMETER, ROUND REPUBLIC ALLOY STEEL BARS



NOTE -

CURVE M SHOWS HARDNESS VALUES FOR SPECIMEN MACHINED FROM BAR AFTER OIL QUENCH FROM 1550°F. AND TEMPERED AT 700°F.

CURVE H SHOWS HARDNESS VALUES FOR SPECIMEN MACHINED FROM BAR AFTER OIL QUENCH FROM 1550°F. AND TEMPERED AT 1150°F.

THE HARDNESS SPECIMENS WERE TAKEN FROM THE POSITION IN THE 12" BARS INDICATED IN FIGURE 1.

A. S. T. M. TENTATIVE METHOD OF END-QUENCH TEST FOR HARDENABILITY OF STEEL (A 255 - 52 T)

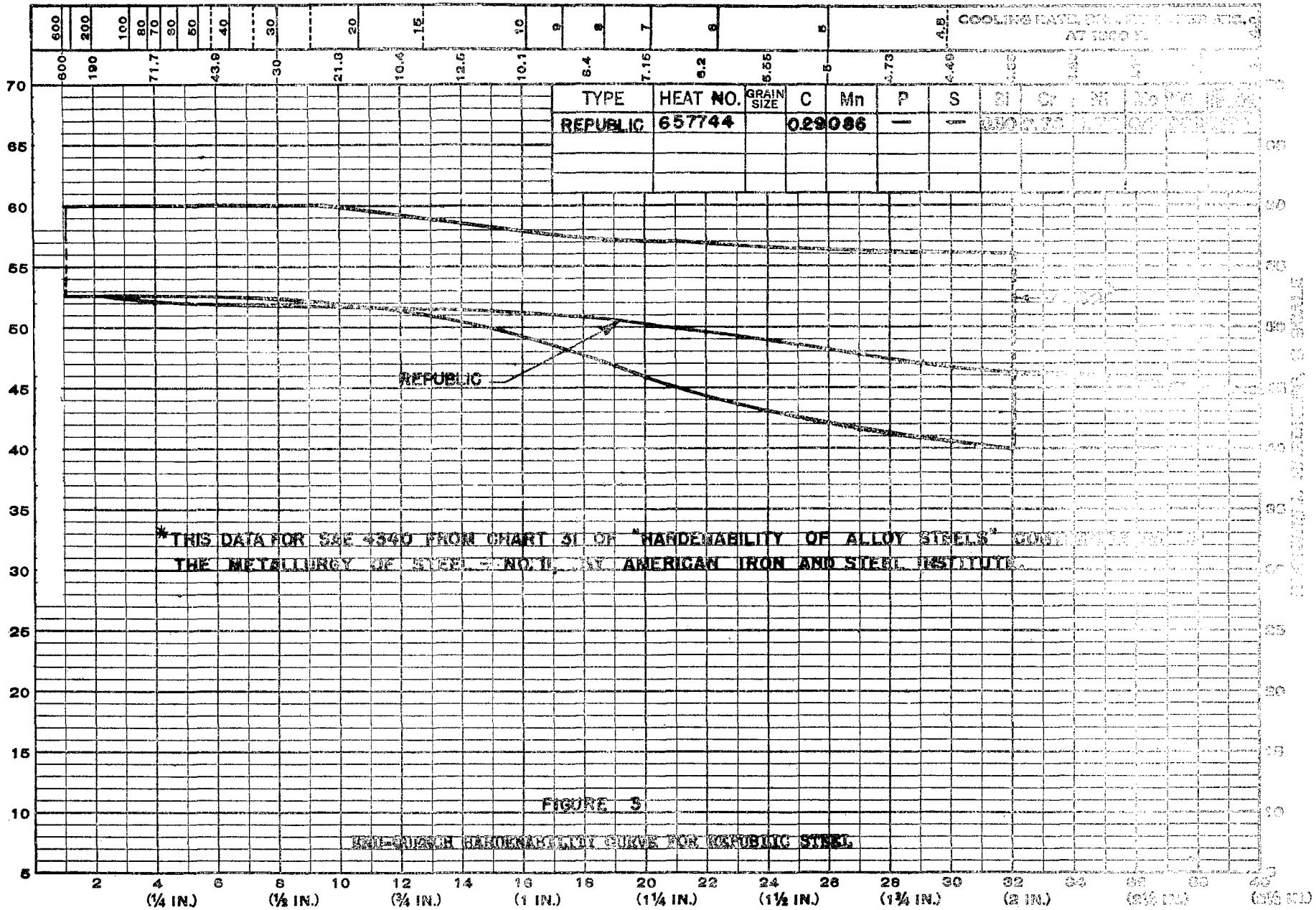
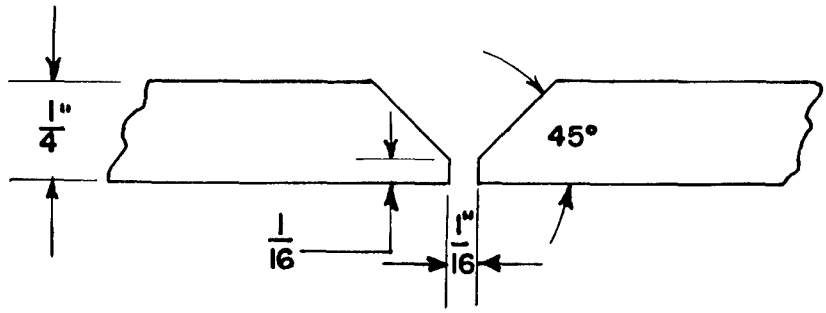


FIGURE 3

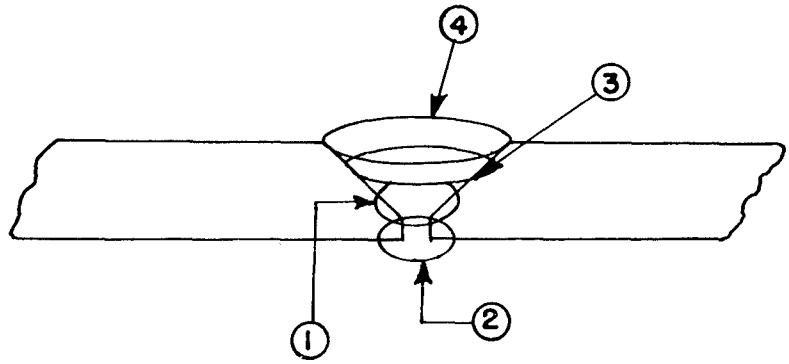
END-QUENCH HARDENABILITY CURVE FOR REPUBLIC STEEL

FIGURE 4

DETAILS OF WELDING PROCEDURE



JOINT PREPARATION



NO. WELD PASSES – 4, NUMBERED IN ORDER MADE.

SCALE: – 2"–1"

WELDING ELECTRODE – P & H # 21 $\frac{1}{8}$" DIA.

PREHEAT TEMPERATURE – 300° F. TO 400° F.

WELDING CURRENT – APPROX. 100 AMPERES.

FIGURE 5

COMPARISON OF TRANSVERSE AND LONGITUDINAL YIELD STRENGTH PROPERTIES OF REPUBLIC ALLOY STEEL. SPECIMENS CUT FROM 4" DIAMETER BAR

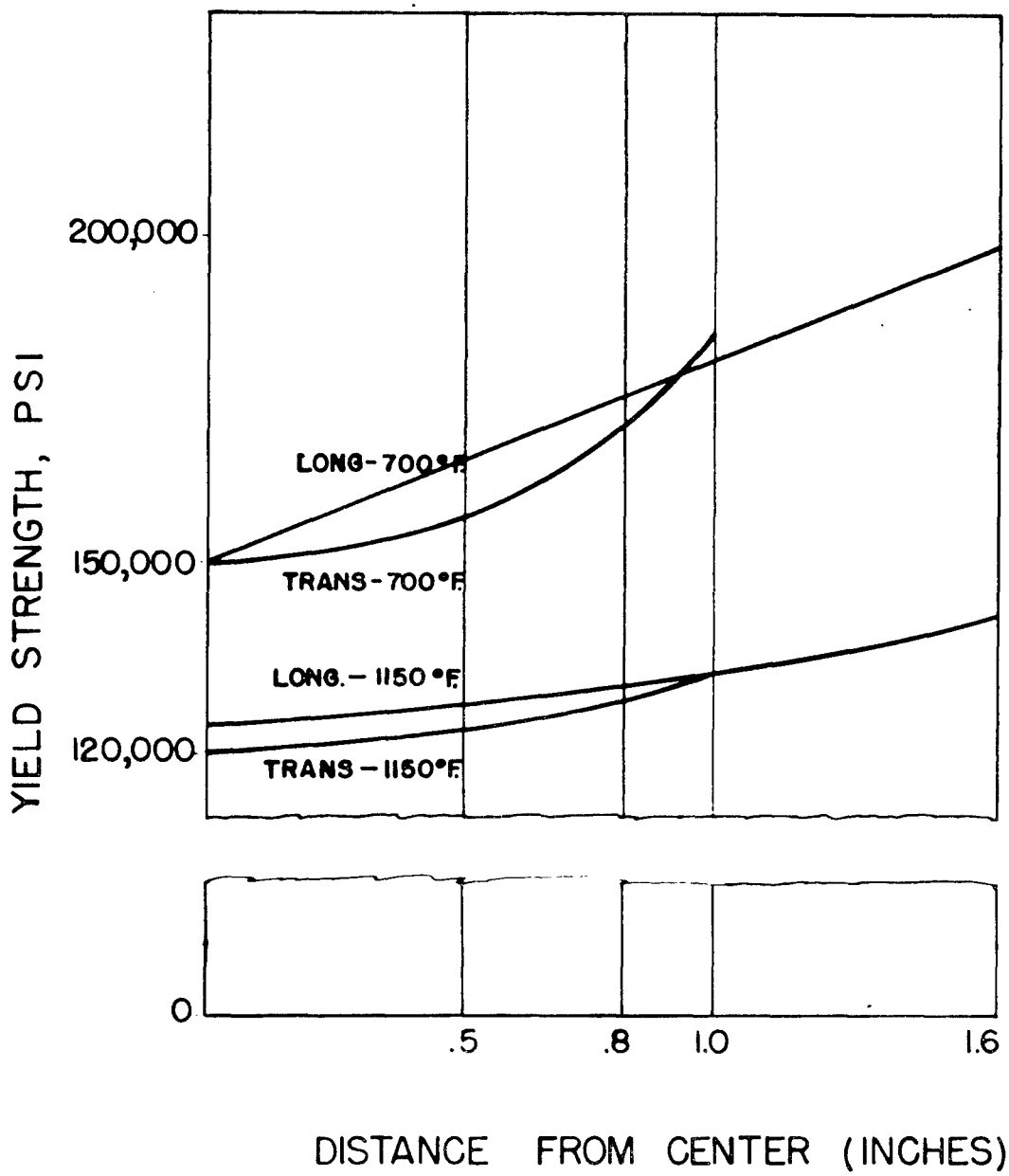


FIGURE 6

COMPARISON OF TRANSVERSE AND LONGITUDINAL ULTIMATE STRENGTH PROPERTIES OF REPUBLIC ALLOY STEEL. SPECIMENS CUT FROM 4" DIAMETER BAR.

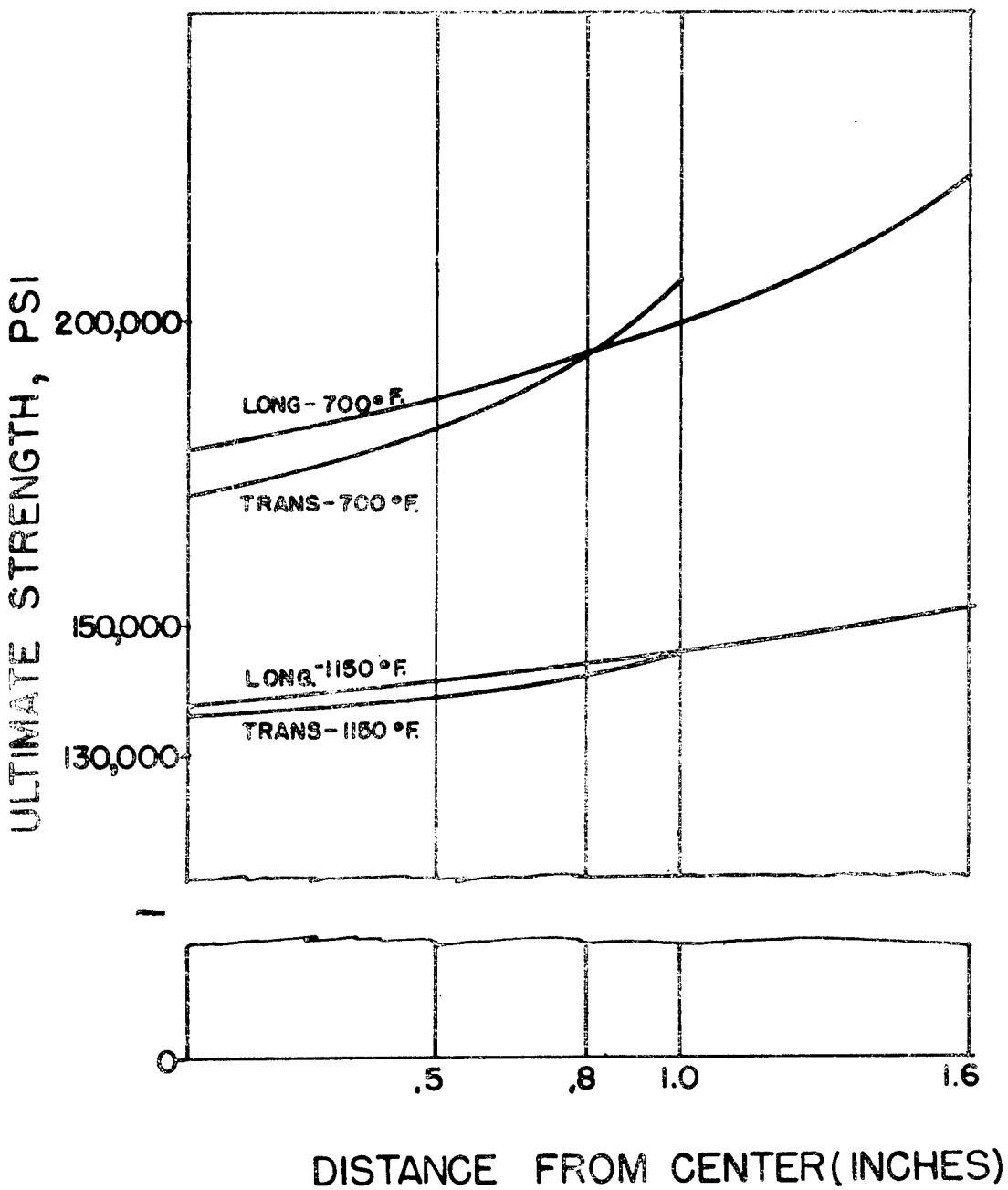


FIGURE 7

COMPARISON OF TRANSVERSE AND LONGITUDINAL REDUCTION OF AREA OF REPUBLIC ALLOY STEEL. SPECIMENS CUT FROM 4" DIAMETER BAR